# Implementation of a Heterogeneous-Reliability Memory Framework

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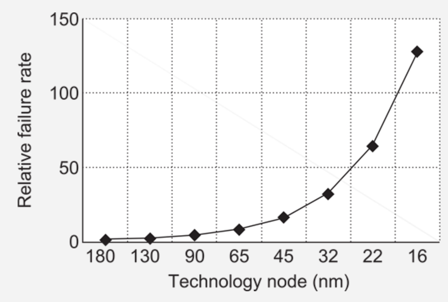
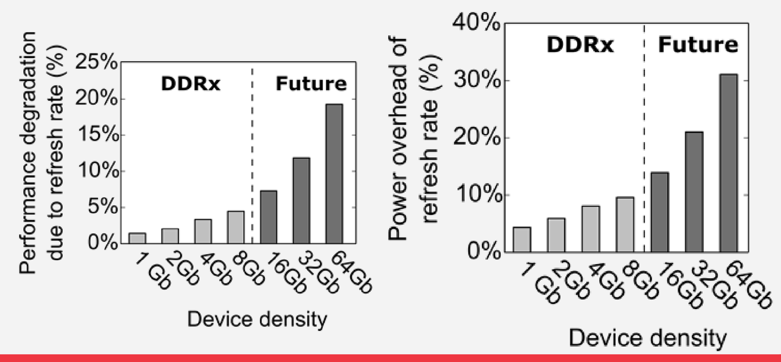
## Motivation

- Nanometer memories are becoming unreliable
  - ➤ Increased failure rates threatening the system



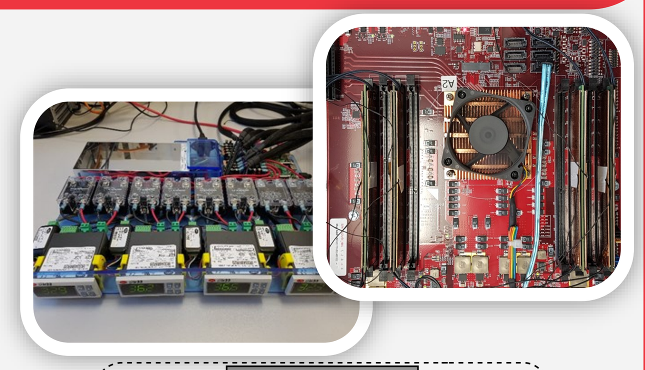

- Conventional approach: adoption of guardbands based on the worst-case scenario
  - ➤ Power and performance overhead
- DRAM consumes up to 40% of the total power dissipation in servers



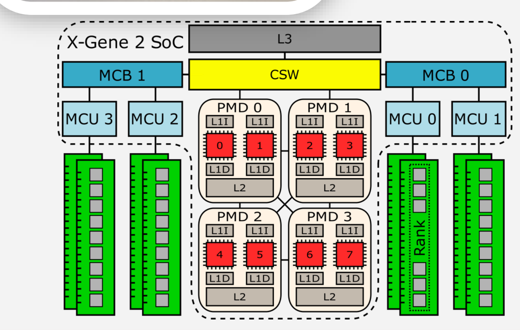

## Experimental Setup

Implemented on a real commodity server

- AppliedMicro X-Gene 2, 8 × AArch64 cores
- 4 Memory controllers (MCUs), 4 × DIMM DDR3 8GB
- CentOS 7, Linux kernel 4.11



Evaluated with 35 workloads (SPEC CPU2006 and NAS)




Parameters of the variably-reliable memory domain:

- Refresh rate: 35x relaxed (64 ms to 2.283 s)
- Voltage: 5% reduction (1.5 V to 1.425 V)

## Proposed Approach

### Heterogeneous-Reliability Memory Framework (HRM)

Separate the memory into two domains and allocate data on each one based on their criticality and tolerance to errors.

| Reliable memory domain | Variably-reliable memory domain |
|---|---|
| • High cost guardbands | • Relaxed DRAM parameters |
| Storage of: | Storage of: |
| • Critical data | • Error-resilient data |

- Existing approaches showcased:
  - the potential gains of HRM on simulators
  - identified the existence of variable criticality of application data

**Challenges**

- ✗ Evaluated only on simulators
- ✗ The existence of hardware-based memory interleaving
- ✗ Disabling interleaving introduces a performance overhead
- ✗ The lack of an intuitive interface for the HRM

## Proposed HRM

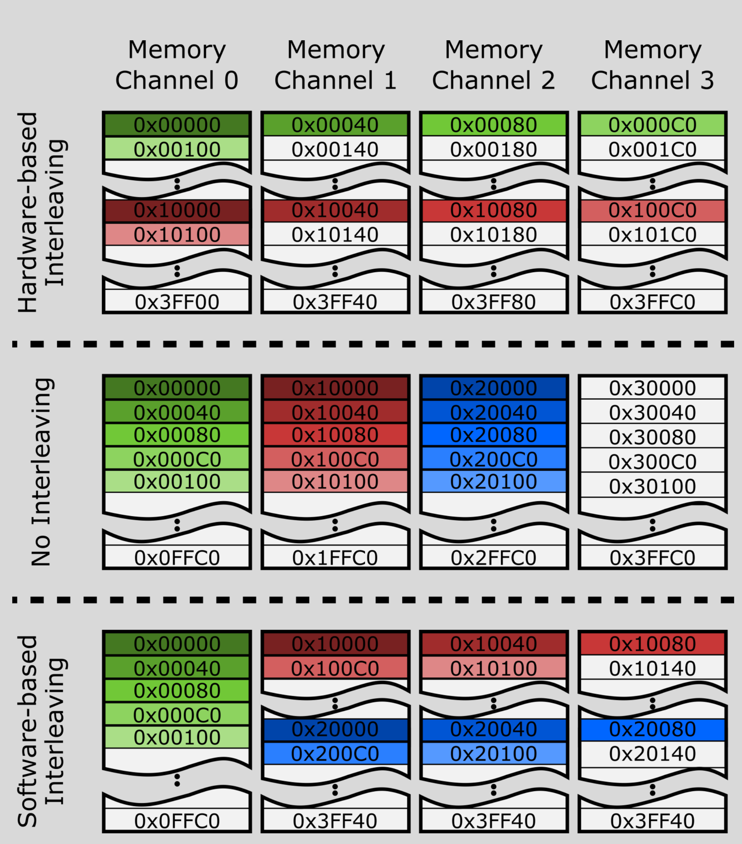
**Interleaving**

Expose and disable the hardware-based memory interleaving on the server

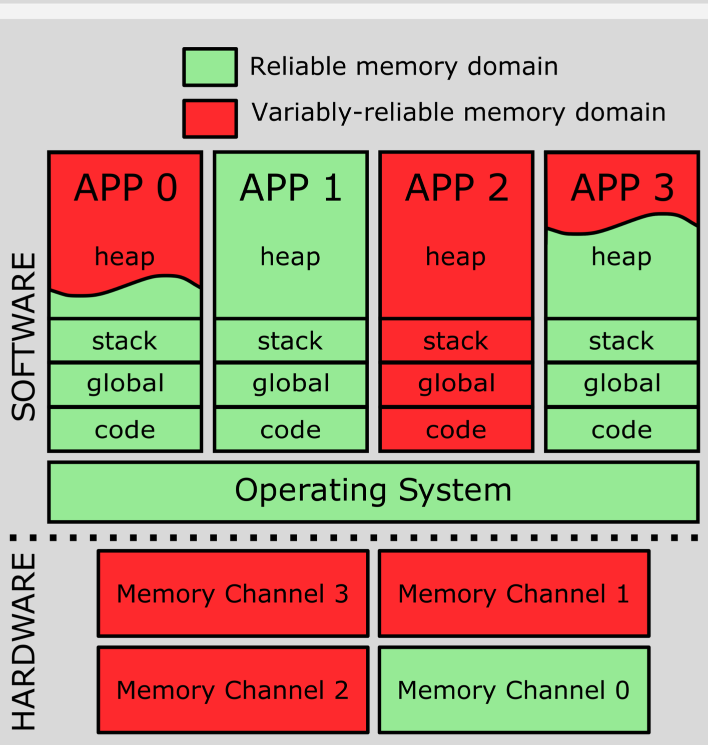
- Enable distinct memory address ranges for each memory channel
- Performance overhead is introduced

Implement a software-based memory interleaving scheme

- Exploit multiple memory controllers for consecutive accesses
- On-the-fly selection of the interleaving function




**Interface**




Introduce an interface for HRM allocations under the Linux OS

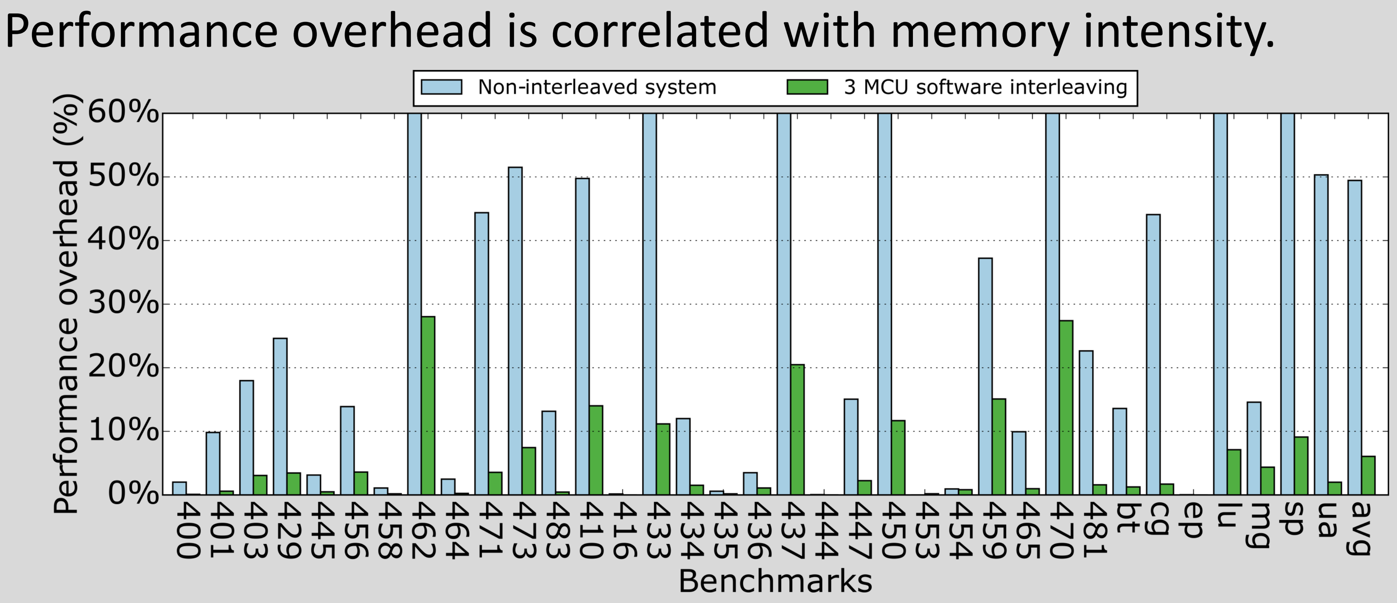
- NUMA interface, `numactl`, to control on application-level (e.g. APP1, APP2)
- Allocation functions, `malloc`, can be replace with `numa_alloc_onnode`, to specify the reliability domain for each allocation (e.g. APP0, APP3)

Enable the selection of software-based interleaving through the same interface

## Experimental Results

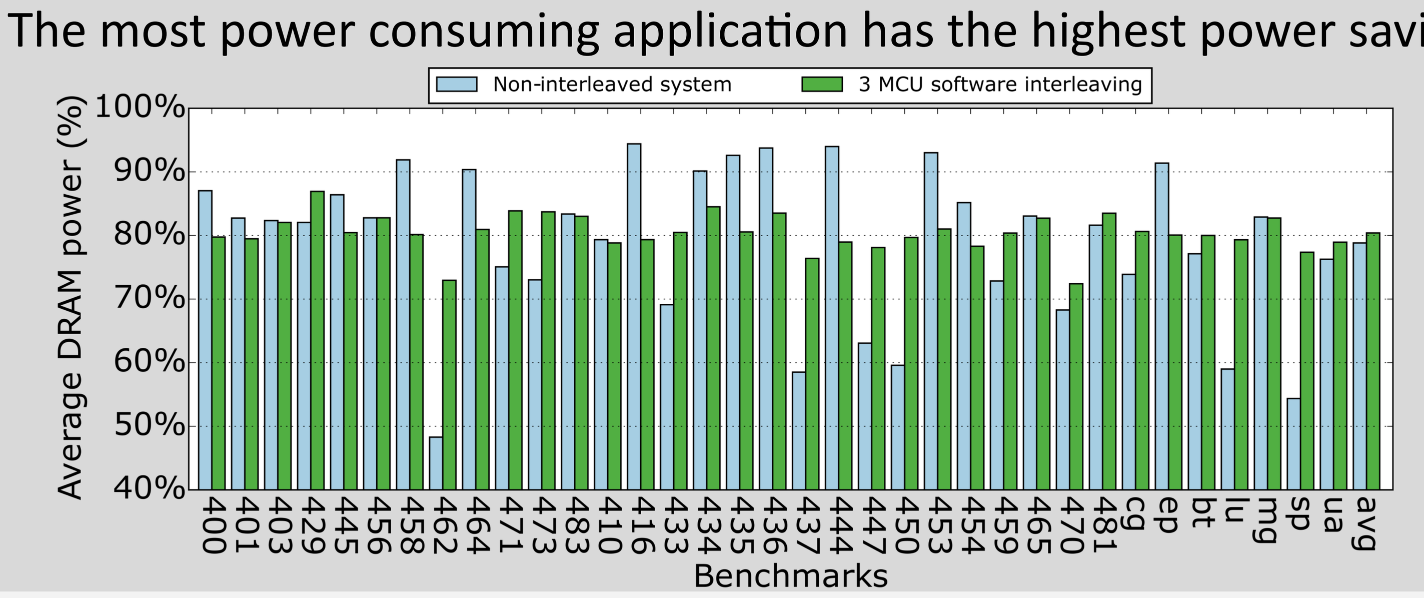
**Performance**

- The naive HRM introduces an average performance overhead of 49% and it reaches up to 128% for `462.libquantum`.
- Our implementation **decreased the average overhead down to 6%** , while `462.libquantum` has the highest overhead at only 28%.
- Performance overhead is correlated with memory intensity.



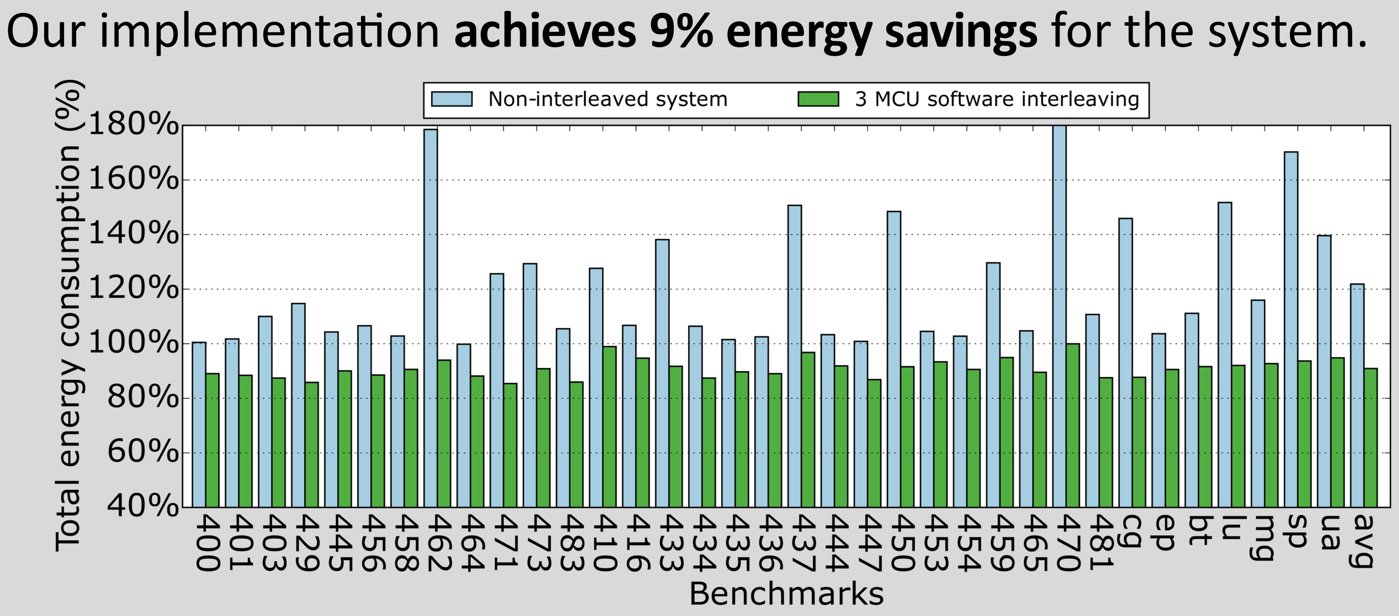

**Power**

- The naive HRM decreases the power consumption by 23%.
- Our implementation **reduces the DRAM power consumption by 20%**.
- The most power consuming application has the highest power savings.




**Energy**

- For the naive HRM, no benchmark achieves any energy savings, and the energy of the system (processor and DRAM) is increased by 22%.
- Our implementation **achieves 9% energy savings** for the system.




**Reliability**

- Under non-controlled temperature, only correctable errors occur in the variably-reliable memory domain, while under high temperature, uncorrectable errors manifest and applications must tolerate them.
- No errors occur in the reliable domain even at high temperature.

## Conclusions

- Implement a heterogeneous-reliability memory framework on a real server.
- Introduce a software-based interleaving technique to mitigate the performance overhead when hardware-based memory interleaving is disabled.
- Obtain 9% energy savings and reduce DRAM power consumption by 20%.
- Enable fine-grain control of the allocation on the reliability domains.
- Ensure that errors will not manifest in the critical data, such as OS data.

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